4th International Conference on
Energy, Environment and Sustainable Development 2016 (EESD 2016)

35. Investigating voltage control capabilities of PV power plant

Abdul Basit[a,*], Faheem Ali[a], Saad Rashid[a], Muhammad Waseem[a], Muhammad Ishaq[a], Saim saher[a]

[a]*U.S.-Pakistan Center for advanced studies in Energy (USPCAS-E), University of Engineering & Technology, Peshawar, Pakistan*

* Corresponding author: abdul.basit@uetpeshawar.edu.pk

Abstract

Conventional power plants are accountable to provide power balancing services for safe and reliable power system operation; whereas photovoltaic (PV) power plants are treated as negative load, indicating their passive role in providing such services. This concept may pose serious concerns to system operators regarding security and reliability of modern power system as large scale integration of solar power may dominate the conventional power. To support the secure and reliable operation of highly PV integrated power system, the large sized PV power plants must be able to participate in power balancing services such as maintaining zero reactive power transfer at point of common connection (PCC) during normal operation and provide additional MVAr's during contingency events. The ability of PV system to contribute in aforementioned services depends on transmission line length and grid strength. This study investigates the ability of the PV system to provide reactive power support for different line lengths. When PV system, due to large line lengths or because of high contingencies, unable to provide the required reactive support the shunt compensating device will be used to provide the required support.

Selection and/or peer-review under responsibility of Energy and Environmental Engineering Research Group (EEERG), Mehran University of Engineering and Technology, Jamshoro, Pakistan.

Keywords: *“Voltage control; photovoltaic (PV); reactive power compensation; shunt compensation”*

1. Introduction

Renewable power generation has increased significantly in the last few decades and progressively being observed as a mainstream electricity supply technology [1–3]. Globally, 178 GW of solar power has been generating power till end of 2014, where 40 GW started operating in 2014. Germany with 38.8 GW has the largest capacity of solar power plants worldwide followed by China (28.2 GW), Japan (23.3 GW), Italy (18.46 GW) and United States (18.28 GW) [4]. To guarantee that increasing installation of solar power does not affect the power system operation, the large sized photovoltaic (PV) systems must fulfil certain regulations. For example; they should regulate reactive power to keep zero reactive power transfer at the point of common connection (PCC) during normal operation, and able to tolerate system disturbances during faults and other system disturbances.

The power balancing services are usually supplied by conventional power plants that are required for reliable power system operation [1–3]. The renewable power plants, namely wind and photovoltaic (PV), are so far exempted from such services and therefore viewed as negative load indicating their passive role in power system operations [5]. However, as in future the renewable power is going increasingly to substitute conventional power plants that might result in reduction of conventional reserve sources as less conventional plants will be operational to share the regulation burden [5]. The reliable operation of large scale renewable power integrated power system might then be at risk unless these power plants are able to support and participate in power balancing services.

To uphold the secure and reliable operation of power system, the Transmission System Operators (TSOs) have placed certain technical requirements known as grid codes. These requirements are for large sized solar power plants connected to the transmission network and the smaller PV systems connected to distribution network are exempted from such services. The PV's are connected to the grid through inverters and the advancement in power electronics have enabled them to provide certain services as conventional power plants, e.g. maintaining zero reactive power

---

transfer at PCC during normal operation and contribute in providing additional MVAr's during abnormal situations or contingencies.

In most part of the world, the PV power plants are installed at locations far away from load centres where long ac transmission lines are used to connect them to the transmission network. The reactive losses due to high current transfer influence the steady state voltage if appropriate compensation is not provided. The electrical system for PV with converter stations developed after advancement in power electronics is capable of meeting the required reactive power support. However, if the PV system is connected via long transmission line than support from shunt compensating devices will be required [6].

This research paper analyses the voltage control capabilities of PV power plant. The ability of controller to support power system with reactive power is investigated for different line lengths and contingency events that result in low voltage. The paper also analyses the reactive power support from shunt compensating devices when controller unable to provide the desired support due to large sized overhead line length or contingency events that results in lower voltages at PCC. This study develops the power system model of 100 MVA in PSCAD/EMTDC where PV system is connected to a weak point on the grid through a transmission line and a transformer. The model along with PV system also consists of shunt compensating device, where both the converters working in parallel tries to maintain voltage at PCC at its nominal range.

2. Power system model

The PV power plant along with its control is shown in the Figure 1. The model consists of dc link capacitor, resistor R_{BR}, switch S_{BR}, IGBTs, filter, transformer and a transmission line connected PV system to the grid. The energy generated from PV is primarily stored in dc link capacitor and converter station then transformed it to an alternating current. The power electronics switch (S_{BR}) controls the resistor (R_{BR}) for discarding the excess amount of energy during contingencies in order to restore the active power balance and safeguard the capacitor and the control system. The filter is designed to remove harmonics after conversion of DC to AC, and the transformer steps up the voltage.

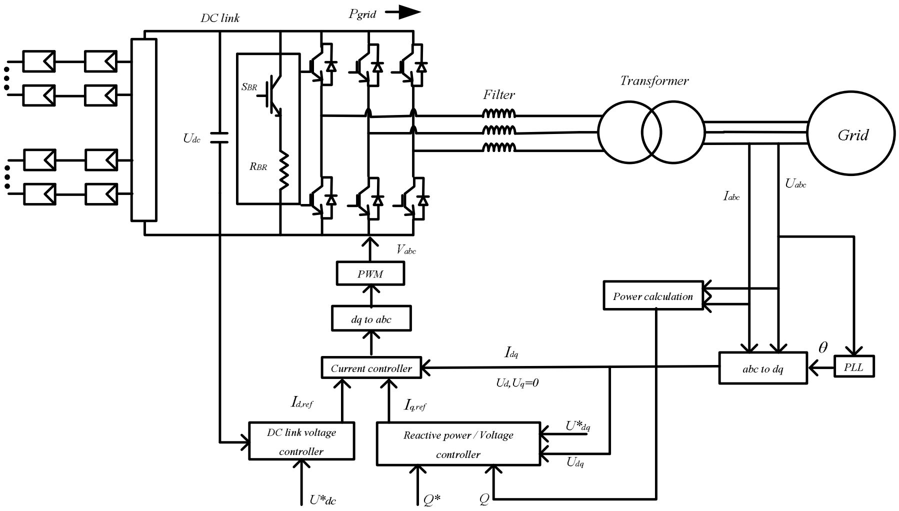

Figure 1: Model and Control of developed power system model

The developed PV system controller consists of current controller, reactive power/voltage controller and the dc link voltage controller. The dc link voltage controller is design to maintain active power balance by regulating the dc link voltage. The reactive power flow is either controller by reactive power controller based on the reference value or by the voltage controller that directly controls the voltage at the specified point. In this study when voltage controller is operational it controls the voltage at PCC. The aforementioned controllers generates the reference values for current controllers.

The designed cascaded control system contains an inner current controller and an outer active power and voltage/reactive power controllers. The inner current controller is designed to control current through filter and transformer while the active and reactive power flow are regulated through outer controllers. The dq reference coordinate system is used in this study for controlling the operation of insulated-gate bipolar transistors (IGBTs) and the voltage and the current are transformed from abc to dq through power invariant transformation. The transformation angle (θ) is provided by the Phase locked loop (PLL) by tracking the grid voltage angle (θ).

3. Analyses of developed PV System model

As VSC is capable of independently controlling active and reactive power, therefore this study investigates the ability of PV to transfer reactive power as transmission length vary while delivering active power of 0.8 p. u. When transmission line length increases from certain level the high reactive losses in the system then results in lagging power factor at the connection point. The shunt compensating devices are then is installed at PCC that can maintain zero reactive power to the converter.

3.1. System capability

The ability of the PV system, while meeting the grid code requirements, to transfer the desired active power without causing any adverse effect on grid performance is known as system capability. To analyse the system capability of developed model while delivering the desired active power, the reactive power transfer is plotted in Figure 2.

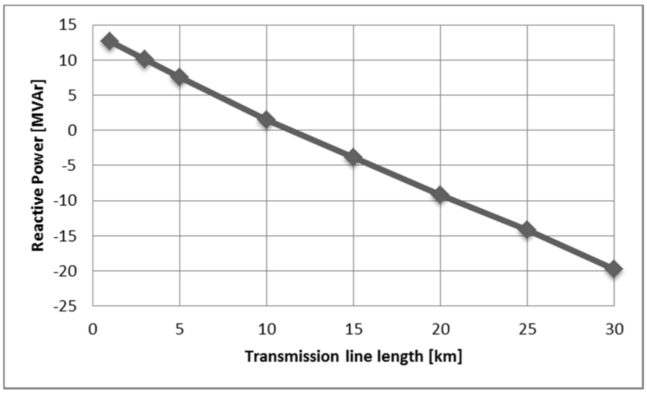

Figure 2: PV system capability to transfer reactive power as function of line length

It can be observed from Figure 2 that for transmission line length of 11 km, desired active power can be delivered keeping zero reactive power transfer at PCC. For smaller lengths extra MVAr's can be provide during contingency events; however, as line length increases than 11 km the high reactive losses will result in lagging power factor at PCC and hence voltage lesser than the nominal level. The later situation negatively impacts the grid performance especially when it is connected at weak point. The shunt compensating device will be required at this point that can provide required reactive power compensation in order to enhance secure and reliable power system operation. The support from the shunt compensating device required for different line lengths is shown in the Figure 3. For transmission line length of 15 km 5 MVAr of compensation is required however when the line length is 35 km the requirement surges to 50 MVAr.

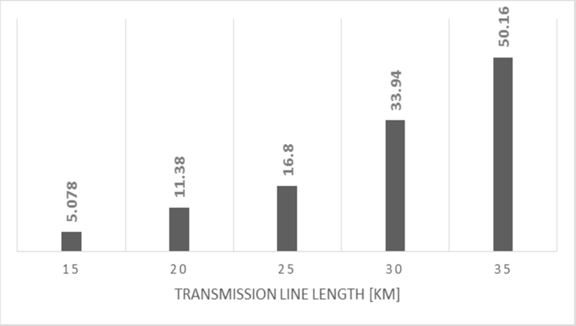

Figure 3 Required reactive power support at PCC for developed power system model

3.2. Dynamic Analyses

During normal power system operation, the PV system is required to maintain zero reactive power transfer at PCC, but increasing large scale integration of PV power plants in modern power system may request for supplementary reactive power support from PVs during contingency events. This study examines the capability of PV converter to supply additional MVAr's when zero reactive power transfer is maintained at PCC. When PV system is connected via 10 km line than response for the following quantities, i.e. active and reactive power and voltage at PCC is shown in Figure 4. It can be observed that there is neither overshoot nor oscillations in reactive power and voltage response; however, due to the change in grid voltage the PLL output is disrupted for short time which results in active power distortion. As aforementioned that during normal operation the shunt compensating device is not connected for 10 km line but as the line length is larger than 10 km than the additional MVAr can only be supplied from shunt compensating device at PCC.

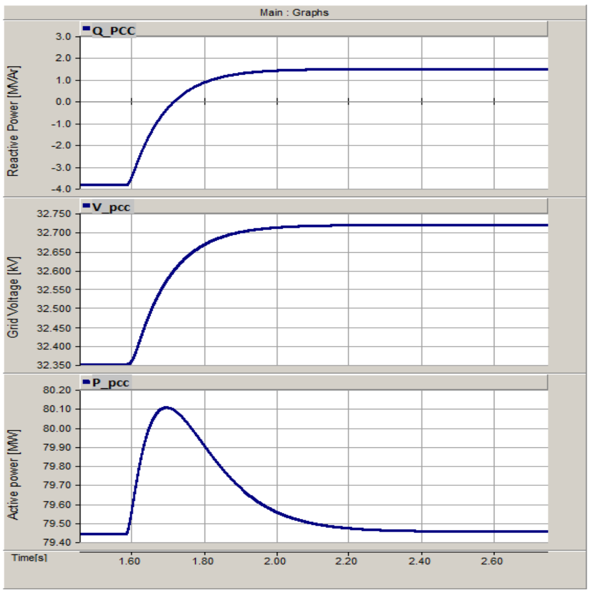

Figure 4: Response at PCC for reactive power step on 10 km line

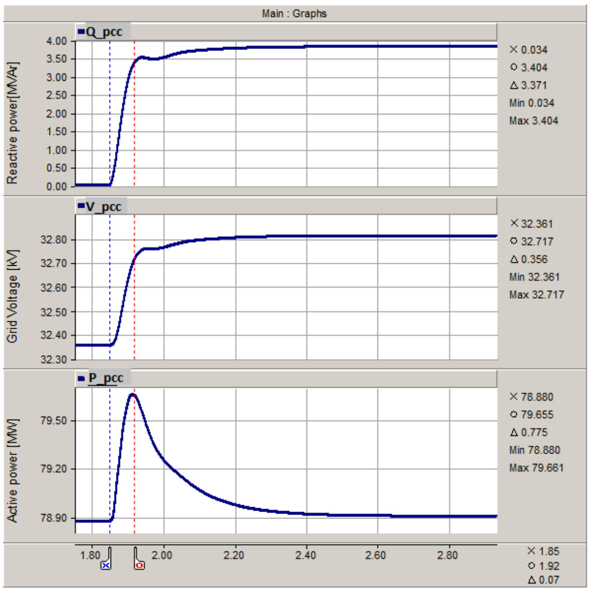

Figure 5: Response at PCC for reactive power step on 20 km line

The reactive power support from the PV system and shunt compensating device is required when the transmission line length is 20 km so that zero reactive power transfer can be maintained at PCC. The additional MVAr's have to be supplied from shunt compensating device. Figure 5 then plots the response of voltage, active & reactive power at the PCC when reactive power step is applied from shunt compensating device. The distortion in active power is due to the change in PLL output while small fluctuations in voltage and reactive power is due to parallel operation of the reactive power controllers of shunt compensating device and PV system.

3.3. Voltage control during contingencies

The PV system controls voltage at PCC through voltage controller by regulating the reactive current, as grid voltage deviates from its nominal level during contingencies. Figure 6 shows the steady state voltage at PCC when grid voltage drops to 0.9, 0.8 and 0.7 p. u. and PV system is connected via 10 km line. Figure 7 shows the active and reactive power at PCC. The PV system delivers the required active power while supporting the voltage at PCC. However, for contingency when grid voltage drops to 0.7 p. u., the reactive power demand is too high that it forces PV system to its maximum current and voltage limit. The controller unable to provide the required support and it results in reduction of active power delivery at PCC.

The TSO's require fault ride through capability from large sized PV power plants and doesn't place any such requirement that it should regulate voltage during contingencies. This study is focussed on modern power systems where TSOs may demand for voltage regulation from PV systems during contingency events that result in sustained low voltages. If PV system has to supply reactive power in order to maintain the PCC voltage at 0.9 p.u. while maintain the desired active power flow the support from shunt compensating device is required most of the times. Figure 8 shows the required support from the PV system and the shunt compensating devices during contingencies on a 10 km line that can retain the PCC voltage within acceptable level.

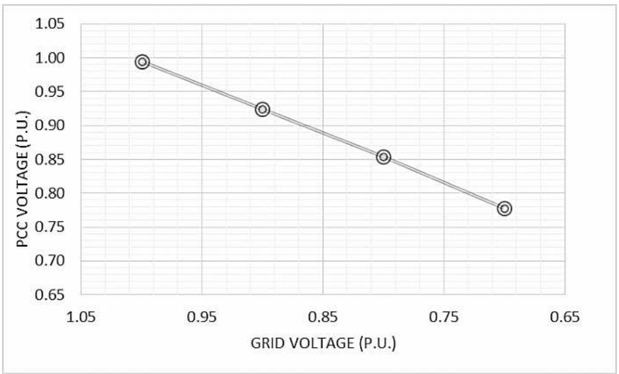

Figure 6: Voltage at PCC during contingency events

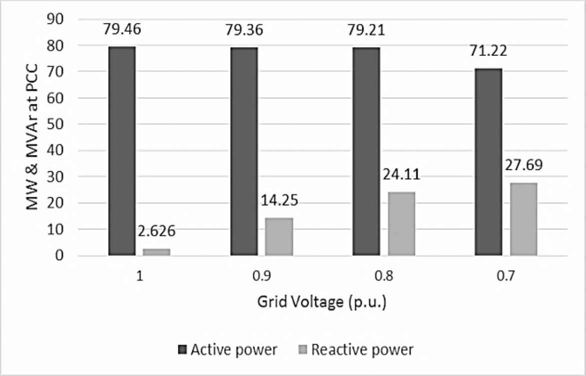

Figure 7: Active & Reactive power at PCC

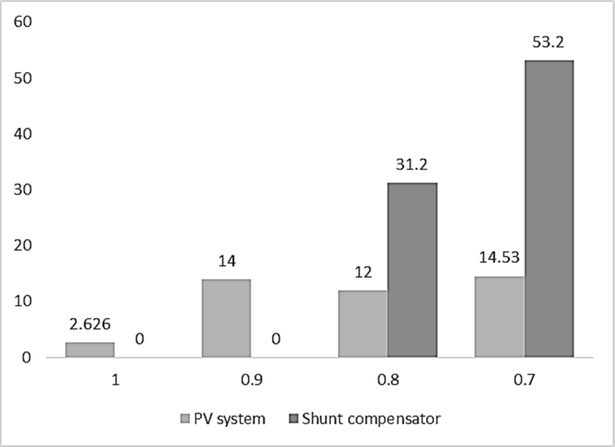

Figure 8: Reactive power support from PV system and shunt compensator when grid voltage drops to 0.7 p. u.

4. Conclusion

This research paper studies the ability of large sized PV power plant to maintain unity power factor, i.e. zero reactive power transfer, at PCC during normal situations and support PCC voltage during contingency events. It can be observed from aforementioned results that PV system equipped with VSC can maintain zero reactive power transfer for certain length of transmission line; however, for higher transmission line length it requires support from shunt compensators. The size of shunt compensator depends on line length and contingency level.

Acknowledgement

We are thankful to USAID for funding U.S.-Pakistan center for advanced studies in energy (USPCAS-E) at University of Engineering & Technology (UET), Peshawar where this research is carried out.

References

[1] A. Basit, A.D. Hansen, et.al., “Wind Power Integration into the Automatic Generation Control of Power Systems with Large Scale Wind Power”, Journal of Engineering (J0E), Institute of Engineering and Technology (IET), 2014, DOI: 10.1049/joe.2014.0222, IET Digital Library.

[2] A. Basit, A.D. Hansen, et.al., “Compensating Active Power Imbalances in a power system with high wind power penetration” Journal of modern power system and clean energy, SPRINGER April 2016, Volume 4, Issue 2, pp. 229-237DOI: 10.1007/s40565-015-0135-x.

[3] A. Basit, A.D. Hansen, et.al., “Real-time impact of power balancing on power system operation with large scale integration of wind power” Journal of Modern Power Systems and Clean Energy, pp. 1–9, DOI: 10.1007/s40565-015-0163-6.

[4] Wikipedia, ‘Solar power by country’, accessed: 22 September 2016, URL: en.wikipedia.org/wiki/Solar_power_by_country

[5] A. Basit, ‘Wind Power Plant System Services’, PhD thesis, Technical University of Denmark, February 2015

[6] Nicholas Miller, et.al., "Integrating Large Wind Farms into Weak Power Grids with Long Transmission Lines," IEEE/PES Transmission and Distribution conference: Asia and Pacific, pp. 1-7, 2005.